Technical Manual on Respiration Chamber Designs

February 2014

Edited by Cesar Pinares and Garry Waghorn

Acknowledgements

This manual has been commissioned by the New Zealand Government to support the goals and objectives of the Global Research Alliance on Agricultural Greenhouse Gases, but its contents rely heavily on the contributions from individual scientists in Alliance member countries. The participation of these scientists and their institutions is gratefully acknowledged and warm thanks are extended for their contribution to this document.

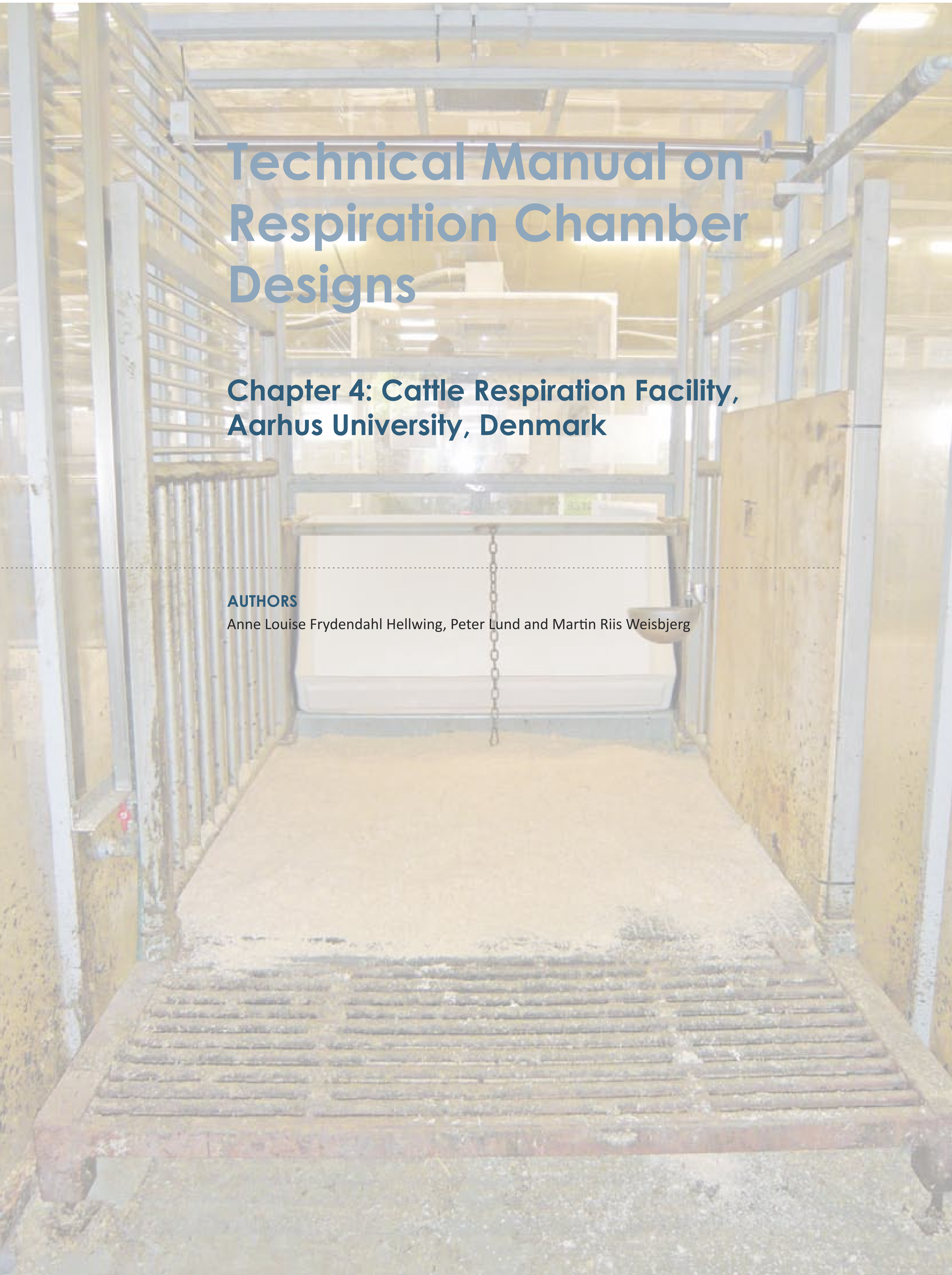
Publisher details

Ministry of Agriculture and Forestry
Pastoral House, 25 The Terrace
PO Box 2526, Wellington 6140, New Zealand
Tel: +64 4 894 0100 or 0800 00 83 33
Fax: +64 4 894 0742
Web: www.maf.govt.nz

Copies can be downloaded in a printable pdf format from http://www.globalresearchalliance.org

ISBN 978-0-478-42361-7 (print)
ISBN 978-0-478-42362-4 (online)
February 2014

Disclaimer



Technical Manual on Respiration Chamber Designs

Chapter 4: Cattle Respiration Facility, Aarhus University, Denmark

AUTHORS

Anne Louise Frydendahl Hellwing, Peter Lund and Martin Riis Weisbjerg

Contents

4.1 Summary

In Denmark, the emission rate of methane from dairy cows has been calculated using the IPCC standard values for dairy cows in Western countries, due to the lack of national data. Therefore, four respiration chambers for dairy cows were built with the main purpose of measuring methane, but also emission of carbon dioxide, hydrogen and consumption of oxygen. The chambers are constructed of steel and polycarbonate. The outside dimensions of the chambers are 183 × 382 × 245 cm, and the volume is approximately 17 m^3. The air inlet is a small gap between the floor and bottom of the chamber. The air outlet is placed at the top of the chamber. The flow rate in the chambers is measured with a mass flow meter. The concentration of gases is measured every 12 minutes with a chemical hydrogen sensor, a paramagnetic oxygen sensor and infrared carbon dioxide and a methane sensor. The ventilation rate for dairy cows is between 800 to 1500 L/min depending on the milk production and liveweight. This gives an average concentration of 5000–6000 ppm of carbon dioxide and 500–600 ppm of methane in the chambers.

4.2 Location of the facility

The physical address of the facility is:

Department of Animal Science
Aarhus University
Blichers Allé 20
DK-8830 Tjele
Denmark

The mailing address:

Department of Animal Science
Faculty of Science and Technology
Aarhus University
PO Box 50
DK-8830 Tjele
Denmark

Contact persons:

1 Peter Lund
Phone: + 45 8999 1131
Email: Peter.Lund@agrsci.dk

2 Martin Riis Weisbjerg
Phone: + 45 8999 1181
Email: Martin.Weisbjerg@agrsci.dk

3 Anne Louise Frydendahl Hellwing
Phone: + 45 8999 1374
Email: AnneLouise.Hellwing@agrsci.dk

The cattle respiration chambers are located at the research centre in Foulum near Viborg which is a part of the Faculty of Science and Technology at Aarhus University. The research centre employs 600 people divided into four different departments. The main campus is located 60 km south east of the centre.

The cow herd counts 200-250 milking Holstein cows plus heifers but no bull calves. The Danish Cattle Research centre is located 1 km from the centre and houses a herd of 210 Holstein and Jersey cows. There is a strong collaboration between the two institutes, and cattle from the Danish Cattle Research centre have been used for experiments in the respiration chambers.

The building housing the respiration chambers was built in 1984 with the purpose of intensive cattle studies (Barn K-33 – see Plate 1). The building is made of bricks with a roof of fibre cement. The walls and roof are insulated according to Danish regulations. The floor is made of concrete, and a slurry drain is placed behind the cows. The slurry drains are covered with gratings behind the cows and with concrete in other places. The slurry drain is emptied two to three times daily with a scraper. The buildings are connected with the other cow barns and feed preparation facilities.

The building can be heated during winter, and the barn has mechanical ventilation. The temperature in the barn during wintertime is normally kept at 14 °C.

The biggest room (K33-1) in building K33 measures 14.4 m x 19.4 m (280 m^2). The height is 2.25 m at the outer wall and 6.6 m in the middle. The volume is approximately 1160 m^3. The barn has room for 2 x 7 tied dairy cows, but normally only eight fistulated cows are housed in this barn section. The other end of the barn had enough room for four respiration chambers. The respiration chambers were established in this barn to reduce the risk of decreasing the feed intake when animals are moved from the tie stall to the chamber. The barn houses other cows, and the barn workers come in to the barn regularly to feed and milk the other cows. Instruments and computers are located in a laboratory right next to the chambers (Plate 1). The laboratory facilities in the barn are used for sample preparation and determination of dry matter.

4.3 Description of the chambers structure

The design of the chambers had to fulfil three criteria:

- Inexpensive to build.
- Ensure an environment without a negative impact on the animal welfare.
- The air inlet had to come from a gap between the floor and the chamber bottom.

The chambers are built for milking cows but calves larger than 250 kg can also be measured in the chambers.

The chambers are built around a platform which was designed for the housing of cattle during intensive metabolic studies (Plate 4).

The laying area is 170 cm long and 165 cm wide and is covered with a rubber mat. Behind the platform there is a slurry grate at 67.5 cm, and underneath the slurry grate a four wheel wagon is placed for manure and urine collection (Plate 5).

The feeding box is placed on a four wheel wagon (Plate 6) with a scale for online recording of feed intake. Water intake is also recorded online.

The chamber is constructed on a frame of 40 x 40 mm steel tube, built around the platform with little space to each side, in the front and behind the platform.

Plate 1: Sketch of the building containing the respiration chambers. The building is connected with the other cattle facilities with a central lane. The cattle facilities include barns for both loose and tied up cattle as well as barns for milking and feed mixing. The respiration chambers are placed in room K33-1 together with fistulated dairy cows. Sensors are placed in laboratory 1.

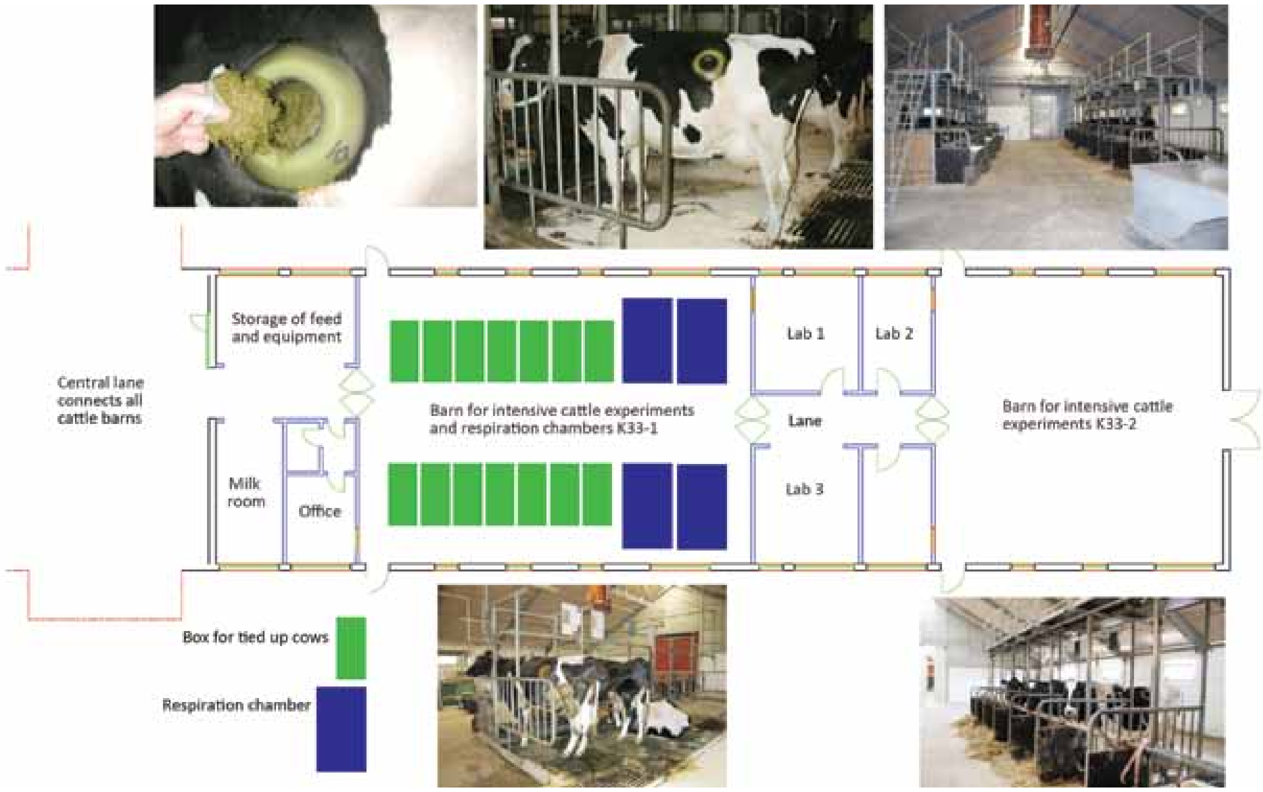
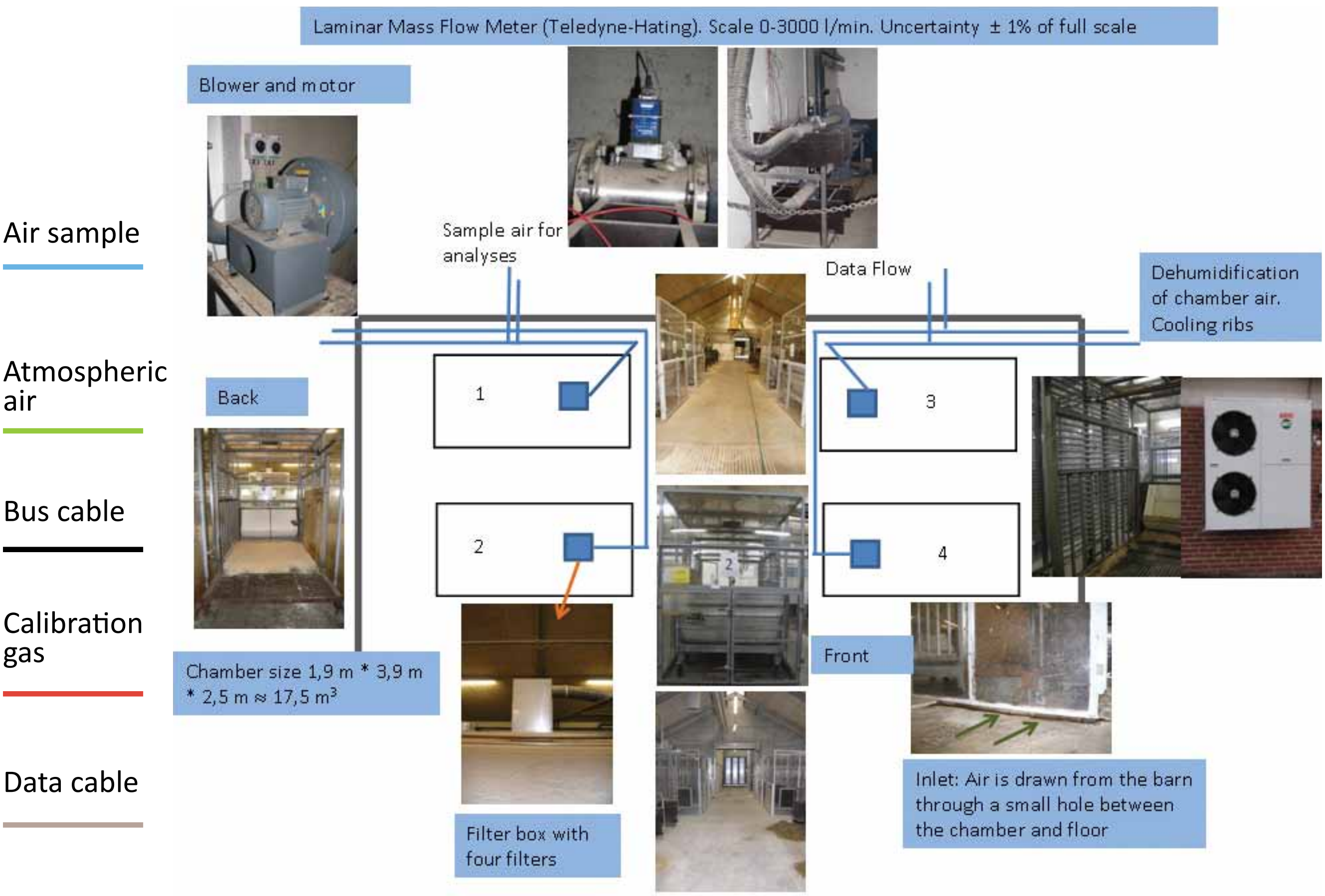


Plate 2: A sketch of K33-1.



The outside dimensions of the chambers are 183 cm (width), 382 cm (length) and 245 cm (height). The chamber volume is approximately 17 m^3.

A 177 cm high double door is placed in the back and a 122 cm double door is placed in the front. Both in the back and front, the doors are closed by a sliding latch and the second door is closed by a lock clamp against the first door (Plate 7) to ensure that the doors are closed. The rear door is for entering during milking, and the front door is for feeding. The edges on the front and rear doors are covered with draught strips.

The chambers are built in two parts which make the transport easier. The metal frame was painted by a professional painter before polycarbonate was mounted. The 6 mm thick polycarbonate is fixed with glue and stopper pins on the steel frame. Polycarbonate and steel have different linear expansion coefficients, and stopper pins are not flexible enough to allow movement of the polycarbonate when the temperature increases. The edges of the two sections were covered with draught strips and screwed together.

The chamber is screwed onto the floor, and the first ⅔ of the side from the front is sealed. The last ⅓ is used as an air inlet. During experiments, the air inlet is sealed with foam rubber (Plate 8) to increase the resistance and thus the air speed (Plates 3 and 8). A smoke test shows that the air movement is slow and that there is no risk that the cow will stand in a draft. It is possible to have a negative pressure when the flow is greater than 1000 L/min. This indicates that the chambers are tight enough and that there are no leakages of air from the chambers to the barn. A smoke test of the chambers shows that the movement of air follows the airstream from the inlet to the outlet.

Each chamber has access to the vacuum and the milk pipe line.

4.4 Animal holding, feeding and cleaning

There is no strict protocol for the operation of the system, and the duration and procedures are planned for each experiment depending on aim, other experiments and labour. Instead, we try to follow a number of guidelines:

- The measurement period should be at least two days and preferably four days. Animals which are measured for only two days will stay in the same chamber. If they are measured for four days they will change chambers (see section 4.10).
- The moving of animals takes place either before or just after the morning or evening milking to reduce the opening time and to ensure the proper estimation of the feed intake.
- The barn workers are instructed to open one chamber and finish work in this before proceeding to the next. The order for fistulated cows is: milking, cleaning, new feed and in the morning also care of fistulas. The total time averages 15−20 min for each cow. The new feed is given just before the chambers are closed. The workers fill in a log book when they open and close the chambers.
- When the chambers contain milking cows, they are usually opened twice a day but only once a day with non-milking animals. On average, we process data for 22 hours/d for milking cows and 23 hours/d for non-milking animals. Milking will normally take place between 05:00 and 07:00 h and between 15:00 and 18:00 h. We always plan an interval of time of at least 10 hours between the milkings.
- All animals are weighed on the way to and from the chambers. The daily milk yield and feed intake are recorded.

Plate 3: Diagram of tubes and cables in the lab.

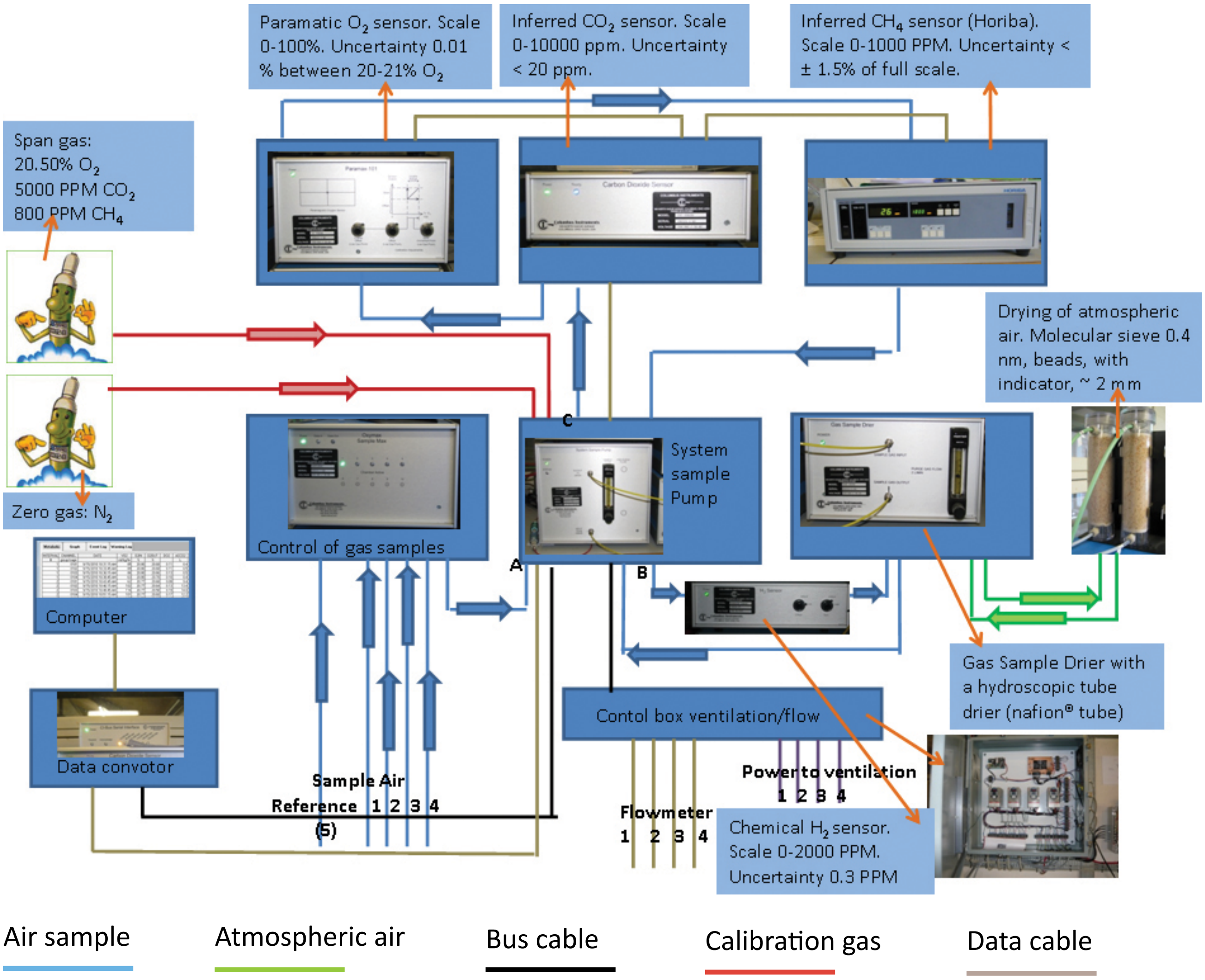
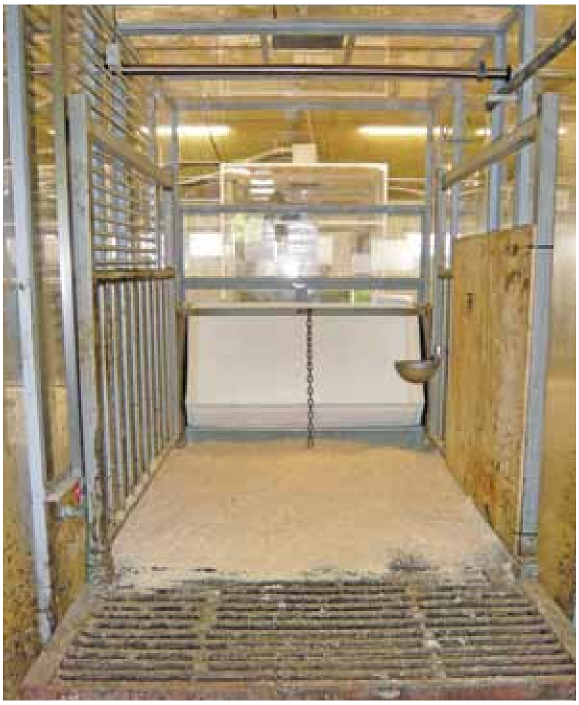


Plate 4: Platform seen from the back.



4.5 Chamber airflow piping and measurement

The flow system consists of:

- A Dayton 2C820 high pressure direct drive radial blade blower with a 0.9 KW motor from VEM motors GmbH (Plate 9).
- The speed of the motors is regulated by an Altivar 31 motor controller (Plate 9) from Schneider Electric by changing the frequency inverters to the motor.

Each motor can be regulated separately. The relationship between the flow and the frequency of the signal to the motor is non-linear. An increase of one hertz will increase the flow more when the flow is increased for instance from 50 hertz to 51 hertz than from 20 to 21 hertz. The flow rate from each chamber depends on the weight of the animal and the production level (milk production or growth) (see Table 1).

Each chamber is fitted with a HFM-200 flow meter, with a laminar flow element from Teledyne-Hating (Plate 9). The flow meters can measure a flow up to 3000 L/min. The laminar flow element has a diameter of 10.2 cm and an accuracy of 1% of full scale, and the repeatability is 0.05% of full scale. The mass flow meter has a shunt and a valve to regulate the air flow.

Table 1: Ventilation rates (L/min) used for animals differing in liveweight and milk production, with expected net concentration of CO_2 of 5000 ppm.

	COW LIVEWEIGHT (KG)						
Milk kg/d	450	500	550	600	650	700	750
10.0	492	516	540	564	588	612	636
12.5	534	564	588	612	636	660	684
15.0	582	606	630	654	678	702	726
17.5	624	654	678	702	726	750	774
20.0	672	696	720	744	768	792	816
22.5	714	744	768	792	816	840	864
25.0	762	786	810	834	858	882	906
27.5	804	876	858	882	906	930	954
30.0	852	876	900	924	948	972	996
32.5	894	924	948	972	996	1020	1044
35.0	942	966	990	1014	1038	1062	1086
37.5	984	1014	1038	1062	1086	1110	1134
40.0	1032	1056	1080	1104	1128	1152	1176
42.5	1074	1104	1128	1152	1176	1200	1224
45.0	1122	1146	1170	1194	1218	1242	1266
47.5	1164	1194	1218	1242	1266	1290	1314
50.0	1212	1236	1260	1284	1308	1332	1356
52.5	1254	1284	1308	1332	1356	1380	1404
55.0	1302	1326	1350	1374	1398	1422	1446

Plate 5: Manure wagon.

Plate 6: Feed wagon.

Plate 7: Lock clamp used to ensure that the front and back doors are closed, and a picture of the front door.

Three things have to be fulfilled to get correct measurements from the flow meter:

- The flow meter must be level. This was ensured when the flow meters, blower and motor were mounted.
- The flow must be laminar through the element. The air runs in a PVC tube before and after it enters the flow meter to ensure a laminar flow. The length of the PVC tube before the flow meter is 60 cm and after 120 cm, which is more than the recommend minimum of 50.7 cm (5 times the diameter of the flow meter).
- The air must be dust free. A 31 x 31 cm filter box is placed at the top of the chamber (Plate 10) to ensure a dust free air. The air from the chambers is drawn through four filters (Plate 11). The first filter is a reticulated foam slab. The next three filters are panel filters. The reticulated foam slab can be washed and the filters are checked regularly and are changed if necessary.

The filter box and PVC tube are connected with a flexible hose.

The chamber air is dehumidified to get rid of the water production from the cow. This is necessary in Denmark, where the humidity is high all year round.

An Ascon Internationel® R407C refrigerating plant at 11.28 kW cools down the water which is circulated through ribs in the chamber (Plates 13 and 14). One refrigerating plant serves two chambers. Furthermore, the dehumidified air decreases the temperature in the chamber by 2–4 ^{o}C because the heat from the condensation of water on the ribs is removed. The temperature is approximately 1–2 ^{o}C above the barn level, and the humidity is approximately the same as in the barn.

Other systems

The temperature, humidity and differential pressure are registered every fifth minute in each chamber during the whole experiment to monitor the climate condition of each cow.

The CO_2 level is monitored in each chamber. If the CO_2 level exceeds 9000 ppm in the chamber or there is a power cut, a GSM modem with an external power supply will phone one of the persons responsible for the experiment (for further details see section 4.9). This CO_2 sensor is independent of the rest of the measuring system.

4.6 Sampling, sample conditioning and analysis

The system can measure five lines. One is used for reference in the barn. We divided the reference line into four tubes in the barn. The tubes are placed the furthest away from the laboratory facilities near the air inlet. The other four lines are used for the chambers. The whole measuring system including the flow meters, the control system for motors and the data acquisition system are delivered by Columbus instruments (Ohio, USA). The measuring system consists of multiport unit switches, a system sample pump, a hydrogen sensor, a sample drier with two drying columns, an oxygen sensor, a carbon dioxide sensor, a methane sensor and a CI bus serial interface. In Plate 3, a schematic outline of the system is presented.

A small sample of air is taken in the middle of the PVC tube between the flow meter and blower (Plate 9). Before entering the measuring system, air is drawn through a Balton DFU® disposable filter. The multiport unit switches the air between barn air (reference) or air from the chambers.

A filter binds the ammonium before it enters the system sample pump. The air is drawn through the system by the system sample pump. The flow in the system is 0.5 L/min.

Plate 8: Air inlet with isolation foam rubber.

Plate 9: Flow system and flowmeter.

Left – Plate 9a: The system. Right – Plate 9b: Flow meter.

Left – Plate 9c: Motor and blower. Right – Plate 9d: Control box with individual motor controller.

Plate 10: Filter box at the top of the chamber.

Plate 11: Filters.

Plate 12: Cooling ribs in the chamber.

After the sample pump, the concentration of H_2 is measured with a chemical sensor.

The next step is the drying of air. The air sample is pumped through an inner tube in the Nafion® tube and dry atmospheric air in the outer tube with a flow of 2 L/min. The atmospheric air is dried in two bottles filled with a molecular sieve (0.4 nm beads, with indicator) that binds water.

After drying, the air is pumped through a paramagnetic O_2 sensor and infrared CO_2 and CH_4 sensors (see Table 2 for details of sensors).

The data from the flow meters and sensors are sent through the CI bus to the computer.

Calibration

Before starting an experiment, all four sensors are calibrated.

The zero point is calibrated with pure nitrogen.

The span point of each sensor is calibrated with calibration gas with a concentration of 20.5% O_2, 0.5% CO_2, 800 ppm CH^4, 150 ppm H_2 in nitrogen as carrier (Table 2). The gas company measures the composition of the gas in the cylinder, and the measured values have a relative uncertainty of 0.2% for O_2 and of 1% for the rest.

Each time the system is calibrated, a log book is filled out to document that the sensors measure correctly. During an experiment, the system is calibrated every second day and always in connection with feeding and milking routines to enable maximum collection of data.

Set up of data acquisition program before the start of an experiment:

- Rinsing of tubes (default 2 min).
- Measuring time (default 30 sec).
- Measurement of the reference (default every fourth time).

The default values of the total measuring time for all chambers and the reference is 12.5 minutes.

The speed of the motors is set to an average CO_2 concentration of 5000 to 6000 ppm in the chambers. This level is chosen because the difference between the outside (barn) and the inside (chamber) has to be as big as possible to reduce the uncertainty of the individual measurements without crossing the upper measuring level of CH_4 and CO_2 sensors in peak periods during the experiment.

Table 2: List of sensors, measuring range, calibration and uncertainty of sensors

Sensor	Principle	Range	Zero/span calibration	Uncertainty
H_2	Chemical	0–2000 ppm	0/150 ppm	0.3 ppm
CO_2	Infrared	0–10,000 ppm	0/5000 ppm	< 20 ppm
O_2	Paramagnetic	0–100%; most accurate between 20–21%	0/20.50 %	0.01 % between 20 and 21%
CH_4	Infrared	0–1000 ppm	0/800 ppm	± 1.5% of full scale

4.7 Gas recovery test

The system is checked regularly, and 35 gas recovery tests have been conducted since establishment in March 2010, until June 2011. The main recovery has been with CO_2 but CH^4 has also been used. The protocol for the gas recovery test is as follows.

Calibration of the system

Adjustment of the gas flow to the chamber with a flow meter to produce an appropriate concentration in the chamber.

The gas cylinders are weighed and placed in the barn, and the tubes are put into the chamber. The CO_2 tube is placed at the top of the chamber. The CH_4 tube is divided into two and placed in the bottom of the chamber.

The measurements are started, and the gas cylinders are opened. To ensure the correct estimation, the decrease in weight of the gas cylinder has to be at least 200 g. The time needed to reach that level depends on the flow from the chambers and the gas concentration in the chamber. Tests with CH_4 take longer than with CO_2.

When the cylinders are closed, the system is given at least one hour to return to barn concentrations and the cylinders are reweighed. The measured accumulations of gases passing through the chambers are compared with measured amounts.

The slope of the decline in gas concentrations after the gas cylinder has been closed, is used to check the chamber volume.

The test results have shown a variation in recovery from 95% to 108% for CO_2 and 90%–110% for CH_4. On average, the recovery has been a little above 100% for both CH_4 and CO_2. (See section 4.10 for further discussions of recovery).

4.8 Emission calculation

The calculation of the methane emission is based on the flow and concentration of the barn air and the outgoing air of the chamber. Until now, no gas recovery correction has been made because the average recovery is approx. 100%. Data deriving from the opening time of the chambers are removed.

CH_4 (L/min) = V_{out} [L/min]* $C_{CH4(out)}$ [ppm]– V_{in} [L/min]* $C_{CH4(barn)}$ [ppm] + delta CH_4 chamber.

Where:

V_{out}: The volume of outgoing air in STP

V_{in}: The volume of ingoing air in STP

$C_{CH4(out)}$: The CH_4 concentration of outgoing air

$C_{CH4(barn)}$: The CH_4 concentration of the reference air/barn air

The Delta CH_4 chamber: The difference of the CH_4 volume in the chamber at the start and at the end of the measurements. The influence on the result will decrease with the increasing duration of the experiment. After 24 hours of measurement, the number is negligible.

The air flow is measured in litres per minute at STP. Only the outgoing air flow is measured. The ingoing air flow can be calculated when the CO_2 and O_2 contents of the outgoing and ingoing air are known. Nitrogen is not used by the animal or excreted by the animal and will be constant. The ingoing airflow can be calculated as follows:

V_{in} [L/min] = V_{out} [L/min]* $C_{N2(out)}$ /$C_{N2(barn)}$

Where:

V_{in}: The volume of ingoing air

V_{out}: The volume of outgoing air

$C_{N2(out)}$: The concentration of nitrogen in outgoing air

$C_{N2(barn)}$: The concentration of nitrogen in ingoing air/barn air

If the respiratory coefficient is one V_{in}=V_{out}. The more the respiratory coefficient differs from one the greater the difference between the volume of ingoing and outgoing air.

The methane production (as well as CO_2 and H_2 production and the O_2 consumption) is calculated for every measuring interval and multiplied with the length of the measuring interval (normally 12 minutes). The calculated production and time of each experiment are summed, and the 24 hour production is calculated.

4.9 Animal welfare and operators' safety

All experiments are approved by the Animal Experiments Inspectorate. The temperature and humidity of the system are automatically registered. If the CO_2 concentration exceeds 9000 ppm or a power cut occurs, the person responsible for the experiment is called. If the blowers stop, the CO_2 concentration will increase at approximately 1 percentage unit per hour, and O_2 will fall at a similar rate. There is sufficient time for the person responsible to get to the barn.

4.10 Weaknesses of the system

There are two main problems in our system. The first is that it is placed in the barn. This causes a fluctuation of the background gas concentrations during the day, so the concentration is not the same for all four chambers. The main reason for placing the system in the barns was to keep the cows in their normal daily environment to ensure that the feed intake was not negatively influenced during experiments. The differences in background gas concentrations are small, and in order to reduce the risk of any influence from background values, the cows change chambers halfway during the four day measuring period. The change is always diagonal so that cows in chamber 1 will be moved to chamber 4. Furthermore, the background problems can be further reduced by increasing the ventilation rate in the barn. This is important during the winter time, when the ventilation rate is low, and the level of methane in the barn can be above 100 ppm. A better mixing of the barn air by a fan will also reduce the problem. The two doors in the barn must be either closed or open to ensure the same concentration all over the barn.

The second problem is the internal mixing of air in the chamber. The only circulation of air in the chamber is generated by the heat from the cow and air change caused by the ventilation system. This is not enough to ensure a total mix of air in the chamber. There are two risks: First, the separation of air in the chamber. Methane is lighter than air and can rise to the top of the chamber, and carbon dioxide can fall to the bottom of the chamber because it is heavier than air. Second, most of the methane and carbon dioxide are expired through the mouth and nose of the cow which will cause a higher concentration in front of the animal. At the rear, the concentration of methane and carbon dioxide is lower because of the air inlet.

The second problem is the most important; there is a little risk of overestimating the methane and carbon dioxide production and differences between treatments will still be correct. The problem could be reduced if a small fan is installed in the chamber for a better mixing of air. These should be placed in such a way that the air from the chamber is not directed out of the chamber through the inlet.

The problems with the background level can explain the fact that the recovery of gasses is not always 100 %. If the background level of CO_2 is ±50 ppm of the measured value it can explain 1–2 percentage points of the difference in the recovery rate. Further, the recovery of gas is dependent on an accurate estimation of the flow. If the uncertainty of the flow meter is 1 % of full scale it would influence the recovery rate with 3 at a flow of 1000 L/min. Therefore, a recovery rate of 90–110 % could be acceptable, but this must always match the flow rate used, the background level in the barn and the chamber concentration of test gas; for instance, if the flow is high, the deviation in recovery must also be low. If the carbon dioxide and methane are run simultaneously, the recovery rate must be nearly the same for the two gasses. If not, it indicates a problem with one of the sensors.

4.11 Description of components and equipment suppliers

Chambers

The chamber frame consists of 40 x 40 mm steel tube covered with 6 mm polycarbonate walls.

The followings parts were delivered by Columbus instruments:

- Four flow meters model HFM-200 with a laminar flow element from Teledyne Hastings instruments that can measure up to 3000 L/min
- Sample controller with valves for control of the gas stream
- System sample pump
- Chemical hydrogen sensor
- Drying system – 2 canisters with drying material
- Infrared CO_2 sensor
- Paramagnetic O_2 sensor
- Infrared Methane sensor VIA 510 from Horiba Instruments INC
- Four Dayton 2C820 high pressure direct drive radial blade blowers
- Four 0.9 KW motors from VEM motors GmbH
- Four inch pvc tubes
- Four inch flexible hose

Other parts

- Cooling plan from Ascon Internationel® R407C at 11.28 Kw
- Stainless steel ribs for cooling water
- Multisensor with 6 channels for CO_2
- Alarm
- Battery for alarm
- Telephone/GSM modem
- Four humidity sensors
- Four temperature sensors
- Four pressure sensors
- Software for locking climate data
- Electrical water counter
- Load cells for feed wagon

4.12 Facility costs

Table 3: Costs of the system, but does not include internal scientific and practical labour costs with respect to planning, establishment and validation of the system.

ITEMS	US$
Four platforms	16,000
Four chambers	40,000
Four air conditioners	32,000
Manure handling	8,000
Feed registration	17,000
Sensors, flow meters, data programme	133,000
Labour (external)	12,000
Test gasses	2,000
Alarm system plus temperature, humidity	20,000
Computer	2,000
Water	2,000
Other expenses	25,000
TOTAL COSTS	**309,000**